

## EFFECT OF SILT ON INCIPIENT MOTION OF GRAVEL PARTICLES

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### ABSTRACT

*This study presents the experimental results on incipient motion for gravel particles in the presence of silt. The channel had a test section of 6.0 m length, 0.75 m width and 0.18 m depth starting at a distance of 7.0 m from the channel entrance. The channel bed of silt-gravel mixture was prepared using dynamic compaction method. The visually observations have been made for the incipient motion of gravel particles in the present study. The beginning of movement of gravel particles in the bed load form is treated as the incipient motion condition. The measurement of discharge, water surface profile, and bed surface profile were taken at an interval of 0.50 m along the flow in the test section of the flume corresponding to the incipient motion condition. The observed value of dimensionless critical shear stress for gravel particles in the silt-gravel mixture is found to be lying below the Shields curve (Brownlie, 1981).*

**KEYWORDS:** Critical Shear Stress, Silt-Gravel Mixture, Incipient Motion, Silt Content

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### INTRODUCTION

Incipient motion in alluvial channel treated as the beginning of the movement of sediment particles from the channel in response to excessive flow that induced shear stress which has a certain critical value. Knowledge on entrainment of sediment particles is significantly important in the study of sediment transport problems like design of stable channel, sedimentation, etc. Judgment of entrainment of sediment particles in alluvial channel is important as it involves parameter identification influencing incipient motion and accordingly formulation developed for determination of critical shear stress and further it will be applicable in modeling aspect in sediment transport. Generally, study of incipient motion carries in two parts i.e. one corresponding to uniform sediment and other for non-uniform sediment. Uniform sediment involves single sediment size having well graded while non-uniform sediment involves mixture of two or more different size particles. Obviously, study on non-uniform sediment is much more complex than that of uniform sediment corresponding to incipient motion. Various studies have been conducted on incipient motion for uniform and non-uniform cohesionless sediments. Several empirical equations have been proposed by the various investigators (Shields, 1936; White, 1940; Iwagaki, 1956; Yang, 1973; Yalin and Karahan, 1979) for the determination of critical shear stress of cohesionless sediments, however, Shields (1936) curve for uniform cohesionless sediment have been used widely for the determination of incipient motion. Mostly empirical equations developed for uniform cohesionless sediment having median sediment size ranges from fine sand to coarse gravels (Garde and Ranga Raju, 2000).

Incipient motion for non-uniform cohesionless sediment mixture was also reported by various investigators (Egiazaroff, 1965; Parker et al., 1982; Patel and Ranga Raju, 1999; Dey and Debnath, 2000). Patel and Ranga Raju (1999) used the mixture of sand and gravel as non-uniform sediment.

Brownlie (1981) proposed an expression for Shields curve for the computation of the dimensionless

critical shear stress of the cohesionless sediment. Brownlie (1981) has proposed the following expression for the computation of dimensionless critical shear stress of cohesionless sediment

$$\tau_{*cm} = 0.22Y + 0.06(10)^{-7.7Y} \quad (1)$$

$$\text{Where, } Y = (\sqrt{(\rho_s - \rho)g(d)^3 / \rho\nu^2})^{-0.6}$$

Here  $\tau_{*cm}$  is dimensionless critical shear stress for the cohesionless sediment;  $\rho_s$  and  $\rho$  are particle and fluid densities ( $\text{Kg/m}^3$ ) respectively;  $g$  is gravitational acceleration ( $\text{m/s}^2$ );  $d$  is arithmetic mean size of the cohesionless sediment (m); and  $\nu$  is kinematic viscosity ( $\text{m}^2/\text{s}$ ).

Kuhnle (1993) conducted an experimental study in a laboratory flume for incipient motion of gravel-sand mixture in proportion of gravel: sand as 0:100, 10:90, 45:55, and 100:0. He found that the critical shear stress for gravel particles in sand-gravel mixture deviated when compared with 100% gravel. Patel and Ranga Raju (1999) proposed a formulation for the computation of critical shear stress of non-uniform fractions in the sediment mixture of sand and gravel that depends upon the size of the sediment fraction, the geometric mean size and the geometric standard deviation of the mixture. Five type of sediment mixture was used in their experiment in which the median size of sediment ranges from 2.0 mm to 4.0 mm. Shvidchenko et al. (2001) presented the results of an experimental study for incipient motion of individual size fraction in sand-gravel composed stream bed. They concluded the parameters governing the incipient motion were ratio of the sediment size to median size of mixture, mixture standard deviation, absolute value of median size of mixture, and the bed slope. Dong (2007) presented a formulation is for determining the relative critical shear stress of sand fraction in a non-cohesive sand-silt mixture. He found that the computed relative critical shear stress increases with the silt content. Patel et al. (2009) modified the formulation proposed by Patel and Ranga Raju (1999). Modified formulation was applicable for both unimodal and bimodal sediments for the computation of critical shear stress of non-uniform fractions in the sediment mixture that depends upon the size of the sediment fraction, the geometric mean size and the geometric standard deviation of the mixture.

Shields curve is considered as the base model for the computation of critical shear stress for uniform and non-uniform cohesionless sediment ranges from fine sand to coarse gravel. However when silt is added to sand then this non-uniform sediment mixture (i.e. silt-sand mixture) behaves significantly different from non-uniform mixture not containing silt. Dong (2007) reported that the behavior of silt-sand mixture is different from the mixture of sand-gravel as critical shear stress moves away from the minimum value on the Shields curve in case of sand-silt mixture whereas for the sand-gravel mixture the critical shear stress moves toward the minimum value. However, behaviors of non-uniform sediment i.e. silt when mixed with the gravel is not yet reported corresponding to incipient motion as per author's best knowledge. Hence, the present study focuses on the behavior of critical shear stress of gravel-silt mixture corresponding to Shields criteria which reflects the effect of silt particles on the incipient motion of gravel particles. The visual observations on sediment movement also affect the formulation for critical shear stress (Ashiq and Doering, 2006). Ashiq and Doering (2006) investigated the incipient motion condition for three different flow conditions namely, (i) when small number of particles starts to move, (ii) when large number of particles starts to move, and (iii) when very large number of particles starts to move and concluded that among the three the condition number (ii) i.e. when large number of particles starts to move is the reliable and realistic approach for incipient motion condition. The present study treated the incipient motion

condition when gravel particles present in the mixture starts to dislodge their position from the channel bed.

## EXPERIMENTAL SET-UP AND PROCEDURE

The experiments were conducted on a tilting flume having 16 m length, 0.75 m width and 0.50 m depth in Hydraulic Engineering Laboratory, Civil Engineering Department, Indian Institute of Technology Roorkee, India. The channel had a test section of 6.0 m length, 0.75 m width and 0.18 m depth starting at a distance of 7.0 m from the channel entrance. The discharge measurement was carried out volumetrically using the tank provided at the end of the flume.

A rectangular trap was placed at the end of the flume just after the tail gate for collection of the bed load. The trap was covered with a net-cloth having fine pores so that bed load retains in the trap. The collected bed load was dried and then weighted.

A two-dimensional bed level profiler having least count 1.0 mm was used to measure the profile of the channel bed. The channel bed profile was also measured by flat gauge of least count 0.10 mm. The water surface profile was measured with the help of a pointer gauge having a least count of 0.10 mm. The bed and water surface profile were measured at longitudinal spacing of 0.50 m along the center line of the flume.

The size distribution of silt and gravel sediment was determined through sieve analysis and plotted as illustrated in Figure 1. The median size ( $d_{50}$ ) of silt and gravel were 0.062 mm and 5.50 mm respectively. The geometric standard deviation ( $\sigma_g$ ) for silt and gravel were 1.18 and 1.31 respectively. The  $\sigma_g$  was computed as  $\frac{1}{2}[(d_{84}/d_{50}) + (d_{50}/d_{16})]$  (Garde and Ranga Raju 2000) where  $d_{84}$ ,  $d_{50}$  and  $d_{16}$  are the sediment size such that 84%, 50% and 16% of material is finer than that size by dry weight respectively. The relative density of silt, sand, and gravel was 2.65.

As the objective of the study is focused on the effect of silt particles on the incipient motion of gravel particles, so in this regard two types of channel bed has been prepared. One is made of gravel particles only while the second one is made of mixture of silt and gravel. For both cohesionless beds the incipient motion for gravel particles were determined on the basis of observed data.

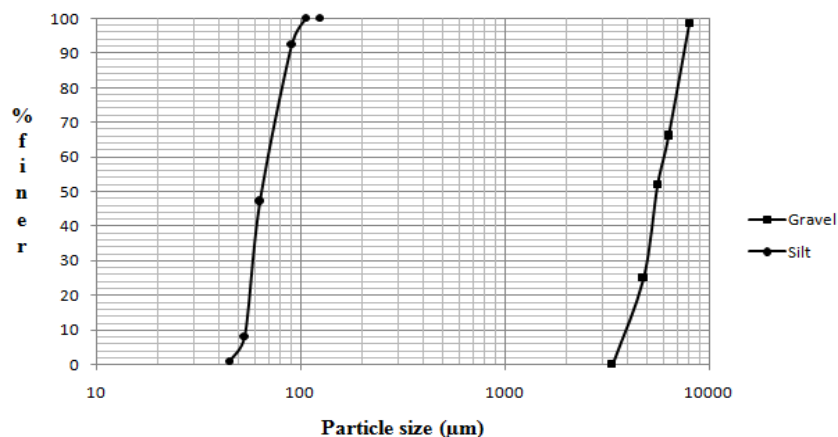


Figure 1: Size Distribution for Sediments Used in the Present Study

In preparation of the non-uniform channel bed, initially the required sediments were weighted (dried) as per equal proportion and then manually mixed together. Water was added to sediment mixture and mixed them thoroughly well. The mixed sediments were covered with polythene and left for 24 hours for uniform water distribution in the mixture. The sediments were mixed thoroughly again before placing it into the test section. The sediments were filled in the test section and compacted in three layers for preparing a channel bed of non-uniform sediment (i.e. silt-gravel mixture). Each layer was compacted with a cylindrical roller having weight equal to 400 N. The sides of channel was compacted by hand rammer having rectangular bottom. To ensure bonding among different layers, the top surface was roughened by trowel before laying the next layer over it. After compacting all the three layers, extra sediments were chiseled off using sharp edge large knife. The final prepared channel bed (shown in Figure 2) was saturated before the beginning of each experimental run.

For each run, a low discharge was initially allowed in the flume and uniform flow was maintained by operating the tail gate. During this process of establishing the uniform flow, the sediment bed was inspected visually in order to examine the detachment of the gravel particles. If no detachment occurred then a small increment in the discharge was admitted in the flume and the bed condition was again inspected carefully. This operation i.e. small increment in discharge and maintaining the uniform flow was repeated till the beginning of the movement of gravel particle occurs. An incipient motion criterion for sediment is based on the visual observations and/or quantitative measurement in terms of low sediment transport rate (Yalin 1972, Parker *et al.* 1982, Wu *et al.* 2000, Kothyari and Jain 2008). The present study includes the visual observations along with the quantitative measurement of sediment transport rate for the reliability in the visual observations. Measurement of discharge, water surface profile, and bed surface profile were taken corresponding to the flow condition of incipient motion. Water and bed surface profile were measured at an interval of 0.50 m along the flow in the middle of test section of the flume from the start of working section. The mean velocity was computed using the measured data of discharge and flow depth. Flow depth was computed as average of difference between the measured bed and water surface profile at middle of each section on 50 cm interval from upstream working section along the flow direction. The shear stress corresponding to incipient motion was computed using measured flow depth and water surface slope profile.



**Figure 2: Prepared Channel Bed of Silt-Gravel Mixture**



**Figure 3: Patches from the Test Section after Incipient Motion Run for Silt-Gravel Mixture**

## RESULTS AND DISCUSSIONS

Incipient motion condition for the gravel particle present in the sediment mixture was visually and quantitatively identified and then the channel bed was visually observed after the end of incipient motion run for the physical appearance of the top bed surface. It was observed that before the beginning of the movement of gravel particle, the fine particle silt was lifted up in the flow and washed away along with the flow as no silt particles were observed at the top surface of the channel bed after the incipient motion run. Figure 3 shows the patches from the test section of the channel bed for silt-gravel mixture which depicts the dominance of gravel particles on the top surface of the channel bed.

The shear stress has been computed on the basis of observed data for flow depth, water surface profile and measured discharge.

Shear stress  $\tau$  is computed as

$$\tau = (\rho_s - \rho)gR'S_f \quad (7)$$

Here,  $S_f$  is the measured water surface slope (-);  $g$  is gravitational acceleration ( $\text{m/s}^2$ ); and  $R'$  is the effective hydraulic radius (m) which is computed as below:

$$R' = \left( \frac{nQ}{AS_f^{1/2}} \right)^{3/2} \quad (8)$$

$$A = bh \quad (9)$$

Here,  $A$  is flow cross-sectional area ( $\text{m}^2$ );  $Q$  is the measured flow discharge ( $\text{m}^3/\text{s}$ );  $b$  is the width of the channel (m); and  $h$  is the average measured flow depth (m) in the test section of the channel.

$n$  is manning's roughness coefficient which is computed as

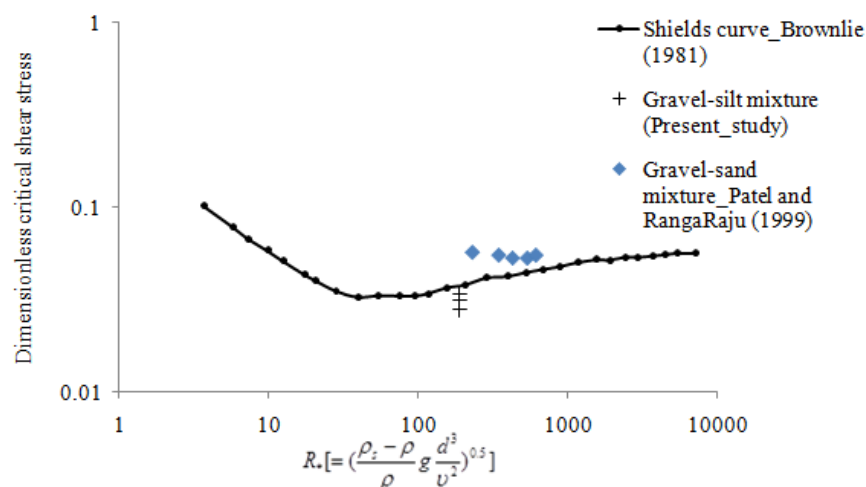
$$n = \frac{(d_a)^{1/6}}{24} \quad (10)$$

Here,  $d_a$  is arithmetic mean size of the sediment mixture (m). With the help of Eqs. (7), (8), (9), and (10) the value of  $\tau$  can be computed.

The behavior of silt-sand mixture of cohesionless sediment for incipient motion reported to be significantly different from the sand-gravel mixture as per Dong (2007). This may be because of the presence of silt in the sediment mixture. To quantify the effect of presence of silt, the observed value of dimensionless critical shear stress of the present study sediment mixture is plotted on Shields parameters as shown in Figure 4 in which abscissa  $R_*[= ((\rho_s - \rho)/\rho)g d^3/v^2]^{0.5}$  is the dimensionless particle Reynolds number. Shields curve drawn on this plot corresponds to the critical shear stress for the cohesionless sediment and the data for the plotting of Shields curve is taken from Brownlie (1981).

The observed value of dimensionless critical shear stress for gravel-silt mixture is lying below the Shields curve as plotted in Figure 4. This may be because of significant difference between the sizes of sediment particles present in the gravel-silt mixture of the study which may responses to early movement of silt particles compared to gravel ones. And due to early movement of silt particles clear water becomes turbid water and it disturb the position of gravel particles in the channel bed which responses to beginning of movement of gravel particles at lower shear stress compared to Shields curve.

The data of Patel and Ranga Raju (1999) has also been used for the comparison purpose as they used non-uniform sediment of sand-gravel mixture. Their data lies above the Shields curve as illustrated in Figure 4 which shows the effect of silt is significantly different from that of sand on the movement of gravel particles. In case of sand mixed with gravel, the void between gravel particles may fill with sand particles which may not come in suspension against the flow as in the case of silt particles. Exposure and hidden effect play the significant role in the movement of gravel particles in case of non-uniform sediment. The less exposure height for gravel particles may available in case of sand-gravel mixture, due to void fill by sand particles, which may leads to higher critical shear stress.



**Figure 4. Variation of Dimensionless Critical Shear Stress with Particle Reynolds Number**

## CONCLUSIONS

The experiments were conducted for the incipient motion of the cohesionless sediment mixture of silt and gravel. In the sediment mixture, the percentage of sediment (i.e. gravel and silt) was mixed in equal proportions. The incipient motion was visually observed for the present study sediment mixture. The beginning of detachment of gravel particles from their position in the bed in the bed load form is considered as incipient motion condition for the gravel in the sediment mixture of silt-gravel. The presence of silt particles in the sediment mixture is studied by plotting the observed value of critical shear stress against the dimensionless Reynolds particle number and Shields curve (Brownlie, 1981) is superimposed on it. Observed value of critical shear stress is found to be lying below the Shields curve (Brownlie, 1981) due to presence of silt particles in the present study of sediment mixture.

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